AD-A093 990 GEORGIA INST OF TECH ATLANTA SCHOOL OF MECHANICAL EN--ETC F/G 11/6
DETERMINATION OF THE TRANSVERSE PROPERTIES OF ESR 4340 STEEL.(U)
SEP 80 J T BERRY DAAG46-78-C-0045

UNCLASSIFIED AMMRC-TR-80-48 NL

1 OF 1
AD A
093990

END
DATE
FILMED
2-81
DTIC

AMMRCTR80-48

DETERMINATION OF THE TRANSVERSE PROPERTIES OF ESR 4340 STEEL

SEPTEMBER 1980

John T. Berry
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Final Report

Contract Number DAAG46-78-C-0045

Approved for public release; distribution unlimited.

Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AMMRC TR 80-48	2. GOVT ACCESSION NO. AD-A093 990	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Determination of the Transverse Properties of ESR 4340 Steel		5. TYPE OF REPORT & PERIOD COVERED Final Report - 3 Aug[redacted] [redacted] 20 Jun[redacted]80
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Professor John T. Berry		8. CONTRACT OR GRANT NUMBER(s) DAAG46-78-C-0045
9. PERFORMING ORGANIZATION NAME AND ADDRESS Georgia Institute of Technology School of Mechanical Engineering Atlanta, Georgia 30332		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D/A Project: 1L62105AH84 AMCMS Code: 612105.H840011
11. CONTROLLING OFFICE NAME AND ADDRESS Army Materials and Mechanics Research Center Watertown, Massachusetts 02172		12. REPORT DATE Sep[redacted]80
		13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Low alloy
4340 Steel
Electroslag remelting (ESR)
Mechanical properties
Fracture toughness

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of the present investigation is to determine the transverse engineering mechanical and fracture toughness properties of electroslag remelted high strength AISI 4340 steel in plate sizes 0.4 inch (10 mm), 1.0 inch (25 mm) and 1-7/8 inch (45 mm) and to correlate these properties with microstructural features.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block No. 20

ABSTRACT

The results of the various tests (Double Ligament, Tensile, and Double Torsion) indicate that the differences between the longitudinal (X) and long transverse (Y) properties of heat 9060 (step-forged 1-7/8 and 1.0 inch plate portions) are at best minor in nature. The same is true with the 0.4 inch-thick cross-rolled ESR 4340 plate (heat 2780). The most significant property differences exist between X and Y direction properties on the one hand and those of through thickness (Z) direction on the other. On comparing the above results with data obtained for heat 9060 at other forging reductions, an increasing sensitivity of ductility (decrease) to increasing reduction is apparent in the Z direction. Scanning Electron Microscope work indicates that the degree of colonization present among the non-metallic inclusions present may be related to the range of ductility-related properties encountered in any particular orientation.

Accession For	
NTIS GRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

GEORGIA INSTITUTE OF TECHNOLOGY

School of Mechanical Engineering

FINAL REPORT

TO: Director
Army Materials and Mechanics Research Center
ATTN: DRXMR-AP, Contracting Administration
Watertown, Massachusetts 02172

Technical Supervisor: Mr. Albert Anctil

FROM: Professor John T. Berry
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

SUBJECT: Final Report
Contract No. DAAG46-78-C-0045
Research Project No. E-25-607
Determination of the Transverse Properties of ESR 4340 Steel
Covering period from August 3, 1978 to June 20, 1980.

DATED: June 20, 1980

John T Berry
John T. Berry
Principal Investigator

S. Peter Kezios
S. Peter Kezios
Director, School of
Mechanical Engineering

W. M. Sangster
Dean, College of
Engineering

Frank O Costello
for Edward E. Renfro
Director, Contract
Administration

PREFACE

The present writer (J. T. Berry) and his students would like to acknowledge the support received from AMMRC during the conduct of the present project. The counsel, cooperativeness and infinite patience of the present monitor, Mr. A. A. Anctil, are worthy of special note. The author must also acknowledge the provision of facilities at Georgia Tech by Dr. S. P. Kezios, Director of the School of Mechanical Engineering, and also the provision of certain specialized test facilities by the Lockheed Georgia Company.

The graduate students contributing to the actual test program were:

Mr. Rudy C. Stotz
Mr. Ravindra H. Ganatra
Mr. Pramod V. Lodhia

Mr. Stotz was responsible for performing the double ligament tests and supervising the tensile testing. He also undertook the scanning electron microscopy (SEM) of the associated fracture surfaces. Mr. Ganatra was responsible for a significant portion of the double torsion and compact tension tests and associated SEM work. He was assisted in these tests by Mr. Lodhia. Early preparatory aspects of test sample production and testing equipment readiness involved two further graduate students, Mr. M. K. Eid and Mr. Hamidi-Sakr.

Finally, special mention should be made of the invaluable cooperative tests conducted by Mr. Oppenheimer, who also supplied so many helpful practical suggestions to the undersigned and his students regarding testing technique, of Messrs. Harry Vaughan and Virgil McCollum who had the arduous task of producing the many specimens involved, and lastly of the incredible efforts of Mrs. Rebecca Rees in the production of the various interim and final report documents.

1. INTRODUCTION

The present investigation was oriented towards the determination of the transverse and short transverse mechanical properties of electroslag remelted AISI 4340 high strength steel ($H_{RC} \approx 58$) in the form of 0.4, 1.0 and 1-7/8 inch (10, 25 & 45 mm) plate.

The properties involved included conventional tensile properties determined using standard ASTM test bars, where such a procedure was feasible and the tensile properties observed using the double ligament test (DLT), which facilitates the evaluation of properties in the Z or through thickness direction in material as thin as 0.20 in. (5 mm) in section. Also included in the tests scheduled were fracture toughness determinations using the double torsion (DT) test, and where applicable the ASTM Compact Tension test.

Fractographic and other metallographic procedures were utilized to correlate the behavior of material in the above tests with microstructural variables.

The present report, which is the final report on this project, describes the results of these tests which were performed on material drawn from two sources:

Plate S-I (0.4 in. material)
Table I - Heat 2780
Plates S-II and -III (1.0 and 1.75 in. material)
Table II - Heat 9060

As will be seen from the tables, plate S-I and plates S-II and -III were drawn from different heats, although both heats were of electroslag remelted grade 4340. The tables also detail certain aspects of the mechanical processing of the plates.

II. SPECIMEN FABRICATION

All specimen fabrication and heat treatment, etc. were to be carried out by the investigating team or by organizations under their direction. No difficulties in machining the as-received mill-annealed 4340 plates were encountered and no problems materialized during heat treatment.

Prior to receiving the plates, a thorough investigation was performed with respect to fabricating and testing AISI 4340 steel DLT bars. Materials from previous ESR 4340 heats, in the form of Charpy bars from 3 x 3, 5 x 5, and 7 x 7 inch forgings were furnished by AMMRC, together with details of the mechanical properties involved. DLT specimens (Fig. 1) were cut from the above Charpy bars and a study made of

(a) grinding and slotting techniques
(b) testing ramifications.

The DLT specimen blanks were marked on their ends with a carbide tipped scriber, assuring proper identification of number and orientation. Simultaneous surface grinding of six (6) blanks was undertaken to insure reproducible flatness and parallelism of surfaces, a 10 inch diameter, 60 grit alumina vitreous bonded wheels being employed on a surface grinder at approximately 1750 rpm. All surfaces were ground to about 0.001 inch oversize, at which point specimens were ground individually to size. Ends of the specimens were cut using a 6 inch diameter 0.015 thick rubber bonded alumina abrasive disc. Examination on a toolmaker's microscope indicated parallelism of sides within 0-25 μ in. and squareness of sides and ends between 0 and 0.007 and 0 and 0.0002 degrees respectively. The surface roughness was better than 25 μ in. Flatness was seen to be ≃ 187 μ in. These latter two measurements were made utilizing a Proficorder (TM) device.

The slotting of the DLT specimens represents a very critical operation. Consequently, a series of dummy slots were prepared utilizing the Charpy bar material referred to above. Previous experience in producing DLT bar slots had employed both high speed steel saws and abrasive discs. Clearly, with the current hardness levels abrasive wheel, EDM or ECM type techniques would appear necessary.

Preliminary tests were undertaken by slotting the above bar using the AL_2O_3 rubber bonded 0.015 inch thick wheel with heavy constraining flanges. Slots were produced as follows:

Slot #1	3450 rpm,	feed 12 ft/min.,	no coolant
Slot #2	3450 rpm,	feed 6 ft/min.,	no coolant
Slot #3	3450 rpm,	feed 6 ft/min.,	with coolant
Slot #4	3450 rpm,	feed 12 ft/min.,	with coolant

Taper sections were then taken of each ligament-like section produced between the above slots. Careful polishing and etching indicated that no burning was present. Microhardness traverses later confirmed this:

TABLE III

Microhardness Survey of Ligaments ESR 4340

Location	Average Microhardness H_V	H_{RC}*
Near Surface of Slot 1	580	54
Near Surface of Slot 2	575	53
Midway Between 1 & 2	535	51
Near Surface of Slot 3	585	54
Near Surface of Slot 4	560	53
Midway Between 3 & 4	525	51

*Equivalent, nearest whole number value.

Tests upon an unslotted Charpy bar section indicated a range of values between 49.8 and 54.1 H_{RC}.

From the above tests it was deemed that the structure of the ligament was not significantly damaged upon slotting. All subsequent bars were produced in this manner.

Fabrication of the DT and CT specimens and of the tensile bars from heat treated material followed normally accepted procedures which are well established. It should be noted the slotting, grooving and notching of the DT and CT specimens, although less critical than parallel operations on the small DLT bars, were conducted with utmost care to ensure that no grinding damage occurred.

III. PRELIMINARY TESTING

Certain preliminary tests were undertaken with the DLT and miniature DT specimens, since the applications of these techniques to a high hardness material represented a new departure.

The results of DL tests on specimens cut from broken Charpy bars drawn from previous heats of ESR 4340 and supplied to GIT by AMMRC indicated that specimen rotation within the clamping arrangement [1] might be a problem in testing. Consequently, all DLT bars fabricated from S-I, II and III were cut to a 1.00 inch length as opposed to the 0.75 in. length used previously (Fig. 1). Clamping bolts of a high strength steel were also utilized in the rig, along with redesigned and specially fabricated clamps hardened to a level slightly above that of the specimens involved.

Turning to the preliminary tests with the miniature DT specimens, several methods were examined for pre-cracking [2] the specimens concerned. The most convenient technique was considered to be that of initiating a pre-crack by fatigue (as in CT testing) rather than by simple bending [2]. All subsequent DT tests had their initial pre-cracks formed this way, although K_Q values are reported for both fatigue pre-cracking and non-fatigue pre-cracking. In the latter case K_Q values were obtained by re-initiating an established crack which itself had been initiated by fatigue. Subsequently, the crack was again stopped and re-sharpened by fatiguing. In this way sequences of fatigue--non-fatigue initiated cracks could be propagated and the associated K_Q values reported on separately [2]. All subsequent DT tests both full scale and miniature were conducted in this fashion.

IV. SPECIMEN LOCATION

The small size of the DLT specimen permits location of the specimen at different depths below the surface of material of the thicknesses currently involved. Consequently, specimens were sampled near the surface and at the center of the sections concerned, as well as in all of the orientations agreed upon in the original proposal:

Ligament Orientation	Code
•Short transverse	TZ & LZ
•Transverse	LY
•Longitudinal	TX

The orientation codes utilized above correspond to those described in the ASME paper referred to previously [1] (Fig. 2).

The location of DT and CT tests followed a similar course; where possible both surface and center material being sampled, together with the various orientations which in this case followed the standard ASTM nomenclature [3].

Applied Stress Orientation	Crack Plane Orientation	Code
Long transverse	Longitudinal plane	T-L
Longitudinal	Transverse plane	L-T
Short transverse	Plane of plate	S-T

Figures 2 and 3 illustrate the orientations involved in DLT specimens and DT/CT specimens respectively.

V. RESULTS

The results of the mechanical property tests performed under the present contract are contained in Tables IV - XV. The tests were performed in conformance with existing ASTM codes where applicable or with practice established previously and described elsewhere [1,2]. (Note: The samples received from AMMRC were numbered SI, SII-1, SII-2, SIII-1 and SIII-2. The subdivision of SII and SIII arises only because two separate samples from each step were received at Georgia Tech.)

The results of the SEM examinations are also described in summary in the following section. (Detailed information is available in references 4 and 5).

VI. DISCUSSION AND CONCLUSIONS

Careful scrutiny of the summary tables describing both DLT and tensile bar data on one hand (Tables VII, VIII, and XV) and fracture toughness data on the other (Tables XI A and B, XII and XIV) indicates, not unexpectedly, that the differences between the longitudinal and transverse properties of heat 9060 (step forging) at various reductions are at best minor in nature. A similar restatement can be made with respect to the 0.4 in. thick cross rolled plate material drawn from heat 2780. It would appear from results of the SEM fractographic work as well as LM examination that the colonization of the relatively small volume fraction of non-metallic inclusions and the subsequent probability of locating such colonies within a particular testbar cross section should lead to a scatter of results (especially elongation and K_Q and in some cases UTS) within a particular orientation (X or Y) for a given forging reduction applied to a given ingot, of the same magnitude as the range of averages indicated. Referring to the DLT data this would appear to be substantiated on comparing the summary data (Table VII) with the ranges which may be seen in Tables IV to VI.

Regarding differences existing between center and surface properties, locations where only one set of DLT data is present* have to be ignored and only sets of data compared. When this is done the breadths of the individual ranges

---

*This situation arose because of limitation in the size of the portions of S-II and S-III supplied by AMMRC.

concerned again come in line with the above remarks regarding effects of orientation (X versus Y). [See Figures 4 (a) and (b)].

The strongest trend which may be discovered when examining the results in toto appears to be the marked difference existing between the X and Y direction ductility related properties on one hand and those of the through thickness (Z) direction on the other. This appears to be present with both the DLT results, and the K_Q data (plate S-III) generated using the miniature DT test. (Refer to Tables VII and XI B.)* When the AMMRC tensile and Charpy data (Tables VIII and IX) are also examined in this respect, it would appear that the expected sensitivity to forging reduction--that is, decreasing ductility with increasing reduction--is clearly present.

The results of the SEM fractography on the DLT bars reported upon by Stotz [4] were to be compared with those obtained on a selection of large scale and miniature DT and limited number of CT specimens, as reported on by Ganatra [5]. All of the specimens examined which were concerned with the fracture toughness testing showed mixtures of the principal types of fracture appearance seen in the DLT specimens sharing 'flat' or normal areas of rupture:

- equiaxed dimple rupture
- quasi-cleavage fracture
- markedly intergranular fracture (with respect to prior austenite grains).

Once again indications of inclusion colonization were present.

No trend could be established regarding the inter-relation of 'local' K_Q values in the DT test with approximate area fractions of a particular type of fracture appearance, possibly due to the 'averaging' effect of the long curved crack front present in this test. (Further test work in this area under rigidly controlled humidity conditions is desirable in the light of recent unpublished work at AMMRC [6].

It may be concluded then from the present results, that while the general scatter in ductility related properties (especially elongation and to some extent UTS) which is related to a particular orientation in a particular forging reduction is of the same general order of the <u>ranges</u> associated with orientation differences in the X and Y plane, a more marked difference exists upon comparing appropriate properties in those directions on one hand with those in the short transverse or Z direction on the other. These differences are more apparent at heavier reductions.

*See also Figure 5.

REFERENCES

1. Oppenheimer, E.D., R. G. Kumble and J. T. Berry, "The Double Ligament Tensile Test: Its Development and Application", Trans. ASME, Journal of Engineering Materials and Technology, April 1975, pp. 107-112.

2. Outwater, J.O., M. C. Murphy, R. G. Kumble and J. T. Berry, "Double Torsion Technique as a Universal Fracture Toughness Test Method", ASTM STP 559, 1974, pp. 127-138.

3. ASTM (1974) Standard Method of Test for Plane Strain Fracture Toughness of Metallic Materials. E 399-74, Part 10, ASTM Annual Standards, Reissued on ANSI/ASTM E 399-78.

4. Stotz, R. MS Project Report 1980, Georgia Institute of Technology, School of Mechanical Engineering.

5. Ganatra, R. MS Project Report 1980, Georgia Institute of Technology, School of Mechanical Engineering.

6. Private Communication from AMMRC via Mr. A. A. Anctil describing unpublished work (1980).

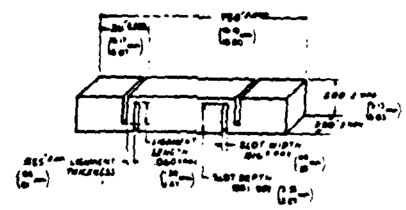


Fig. 1 Detail of double tensile ligament specimen

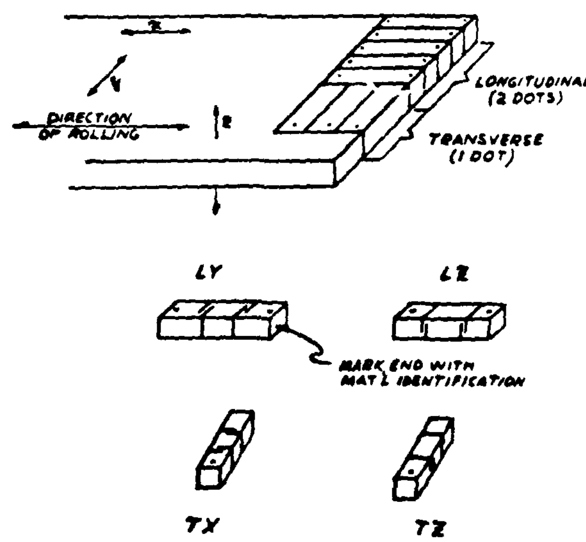


Fig. 2 Specimen identification and nomenclature
(DLT specimen)

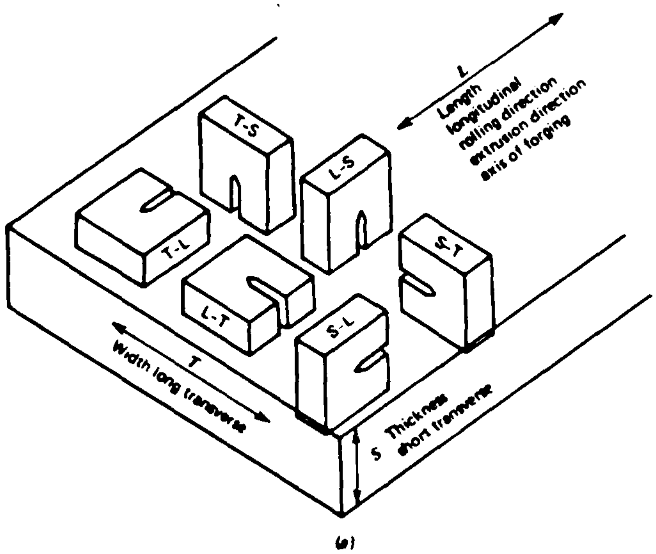
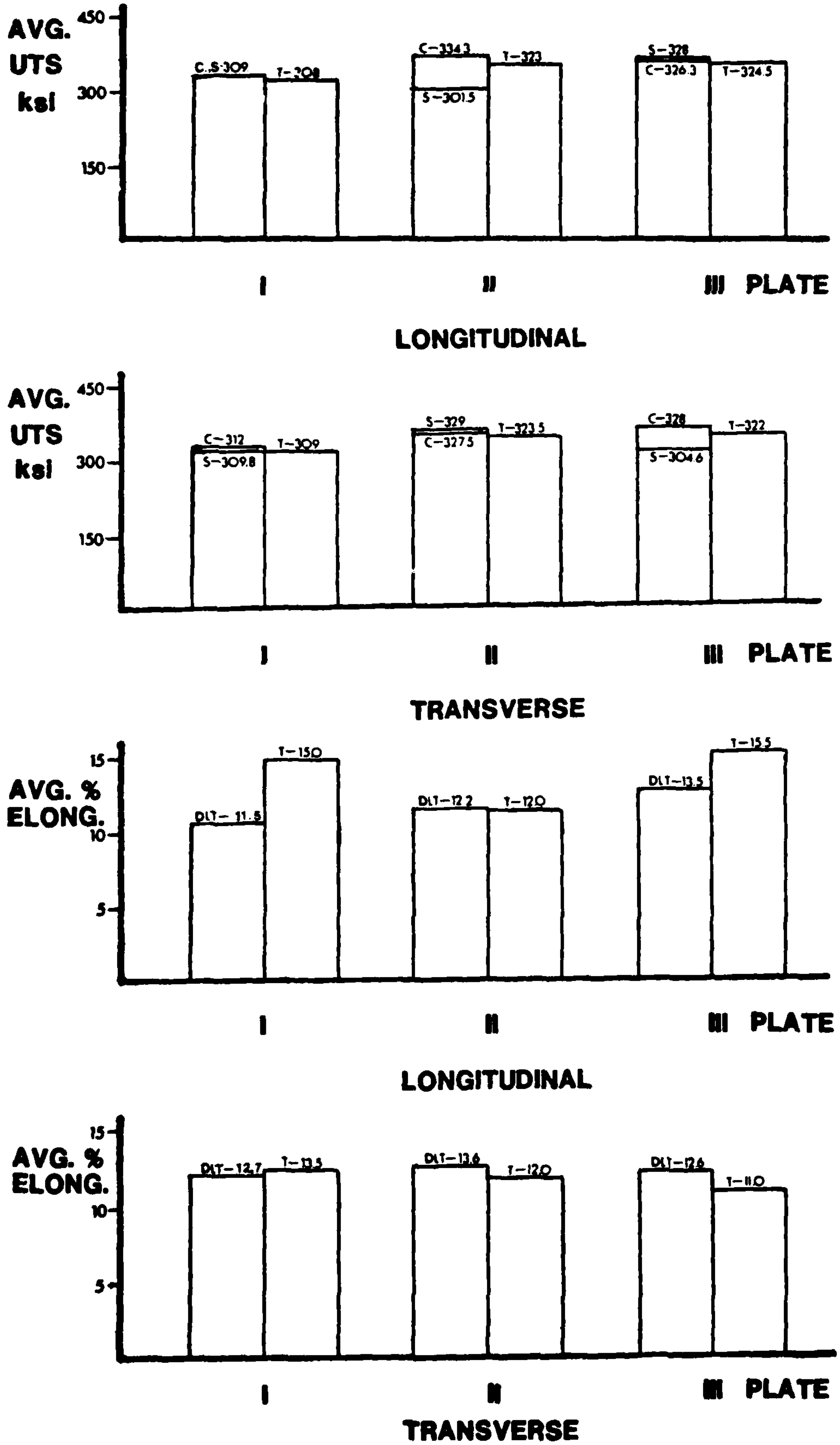


Fig. 3--Specimen orientation
CT and DT specimens.

Fig. 4 (a) **AVG. VALUES FOR UTS AND AVG.% ELONGATION BY PLATE THICKNESS, LOCATION, AND ORIENTATION**



KEY

C - CENTRAL DLT SPECIMENS

S - SURFACE DLT SPECIMENS

T - TENSION SPECIMENS

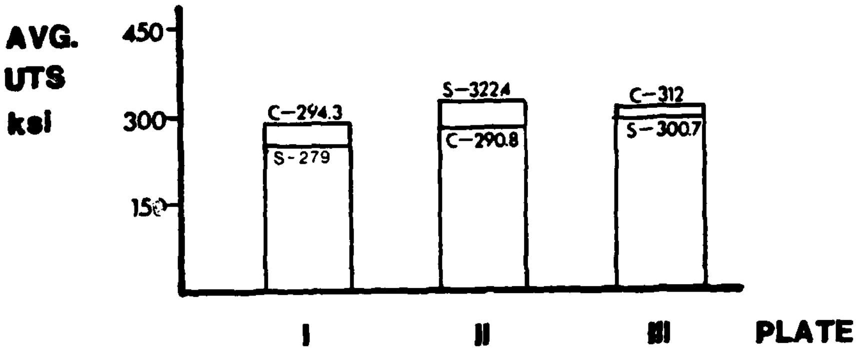
I - 0.4 in. PLATE THICKNESS

II - 1.0 in. PLATE THICKNESS

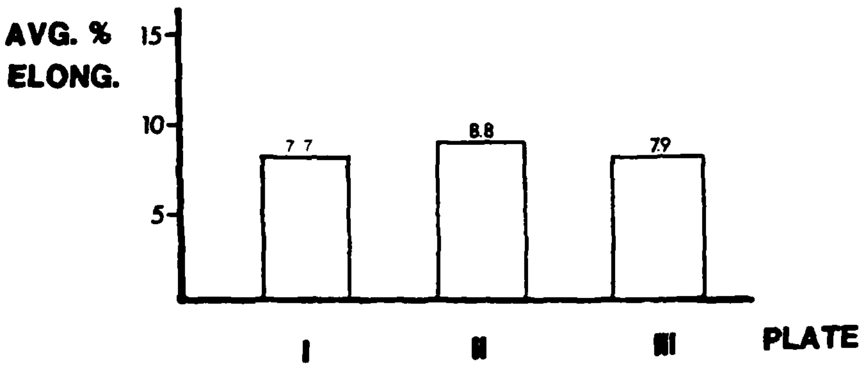
III - 1.875 in. PLATE THICKNESS

Fig. 4 (b)

SHORT - TRANSVERSE PROPERTIES



SHORT TRANSVERSE



SHORT TRANSVERSE

KEY

S - SURFACE DLT SPECIMENS

C - CENTER DLT SPECIMENS

I - 0.4 in. PLATE THICKNESS

II - 1.0 in. PLATE THICKNESS

III - 1.875 in. PLATE THICKNESS

Fig. 5

FRACTURE TOUGHNESS OF (ESR) AISI-4340 STEEL USING DOUBLE TORSION & COMPACT TENSION TEST METHODS

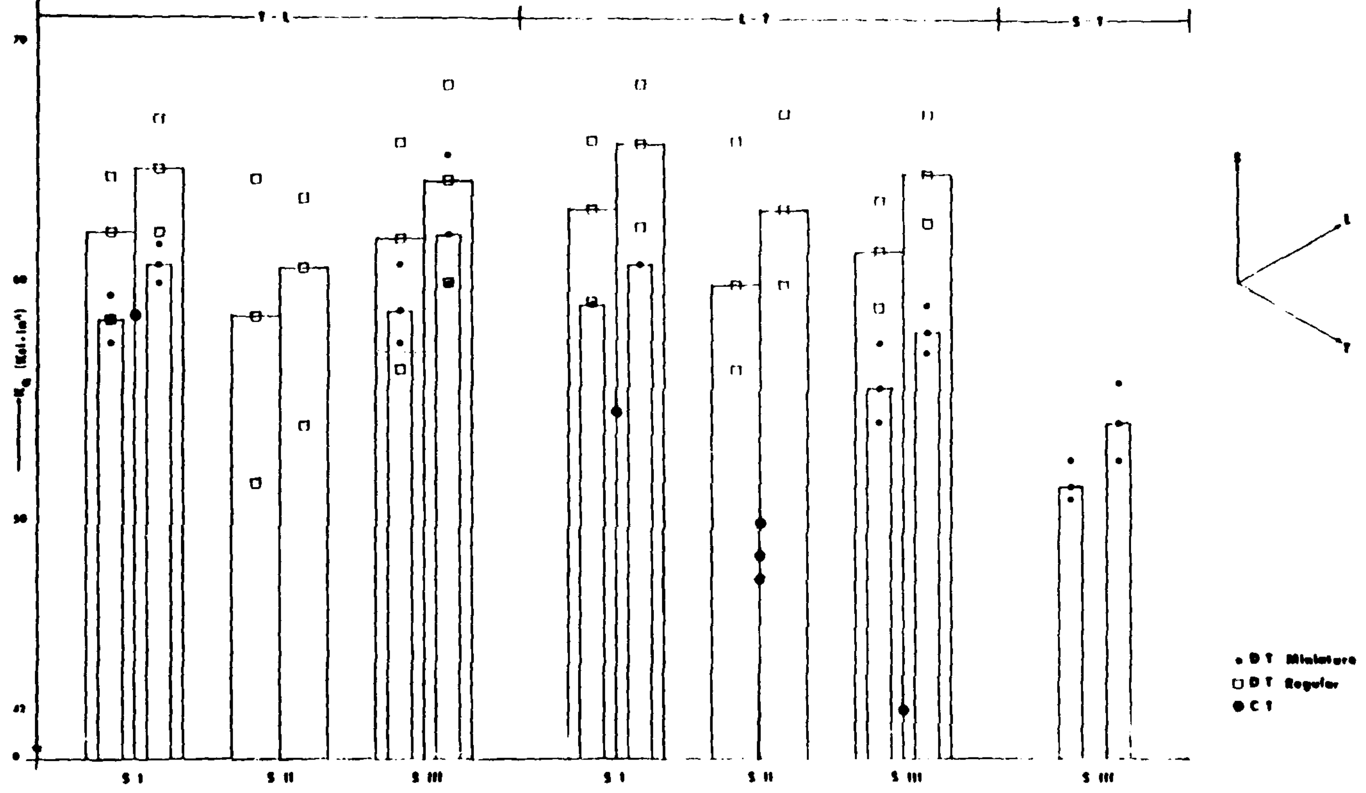


TABLE I

Chemical Composition and Mechanical Processing Details
Plate S-I ESR AISI 4340 Steel (Heat 2780)

Chemical Composition

C	Mn	Si	P	S	Ni	Cr	Mo	V*
0.40	0.77	0.20	0.010	0.003	1.69	0.85	0.24	0.003

Al*	As*	Sb*	Sn*	O+	H+	N°
0.008	0.006	0.004	0.016	0.0011	0.00005	0.0130

Processing

- 20 inch diameter ingot reduced to 12 inch round cross section at 2030 F.
- Pressed to 12 x 5 inch, cross rolled to 0.4 inch thick plate, annealed.

Notes

* Spectrochemical method
\+ Vacuum fusion technique
° Semi-micro Kjeldahl distillation

TABLE II

Chemical Composition and Mechanical Processing Details
Plates S-II and -III
ESR AISI 4340 Steel (Heat 9060)

Chemical Composition

C	Mn	Si	P	S	Ni	Cr	Mo	V
0.40	0.82	0.25	0.007	0.002	1.76	0.84	0.26	<0.02
Cu	Sn*	Sb*	As*	O+	H+	N°		
0.11	0.004	0.004	0.010	0.001	0.0003	0.008		

Processing

- 20 inch diameter ingot forged to 9½ inch diameter cross section, machined to 8½ inch diameter by 16 inch
- Soaked at 2350 F, upset to 10 inch long and forged to 8 x 7 inches. Step forged (S-III ≈ 1.9 inch step)
- Annealed 1600 F--8 hrs., FC to 1200 F over 12 hrs. followed by AC to ambient

  Part of above step (1.9 inch) forged at 2050 F to 7 x 9½ x 1 inch plate (S-II ≈ 1.0 inch)

Notes

- * Spectrochemical method
- \+ Vacuum fusion technique
- ° Semi-micro Kjeldahl distillation

TABLE IV

MECHANICAL PROPERTIES DETERMINED BY DLT TEST FROM PLATE (S-I) OF AISI 4340 STEEL (H_{RC}≈57) W.R.T. TO LOCATION AND ORIENTATION

TABLE IV

PLATE #	S-I							
SPECIMEN #	LOCATION	ORIENTATION	YIELD STRENGTH σ_{ys} (ksi)		ULTIMATE STRENGTH σ_{UTS} (ksi)		ELONGATION % e	
			RANGE MAX.-MIN.	AVERAGE σ_{ys}	RANGE MAX.-MIN.	AVERAGE σ_{UTS}	RANGE MAX.-MIN.	AVERAGE % e
3; 5; 15; 16; 18.	C	TX	216 → 204	208.75	314 → 298	309.2	11.12 → 9.58	10.58
2; 6; 14; 20; 22.	C	LY	201 → 197	195.5	322 → 299	312	14.93 → 11.54	13.54
1; 7; 17; 21.	C	TZ	209 → 195	200.67	308 → 271	294	12.52 → 4.26	8.58
B; 4; 19; F.	C	LZ	216 → 195	204	311 → 262	294.5	10.82 → 6.01	9.04
11; 13; 25; 26; 29; J.	S	TX	245 → 182	212	334 → 283	309	16.74 → 7.79	12.6
9°; 23; 27; 28; 32.	S	LY	223 → 194	206.67	315 → 302	309.75	13.38 → 10.82	12.21
C; 8; 10; 24; 31; G.	S	TZ	217 → 176	196.4	321 → 255	283	11.23 → 4.59	6.72
12; 30; H; D.	S	LZ	233 → 195	219.67	306 → 255	274.75	15.47 → 3.39	7.1

°Invalid test.

TABLE V A

TABLE V A

PLATE #	S-II 1							
SPECIMEN #	LOCATION	ORIENTATION	YIELD STRENGTH σ_{ys} (ksi)		ULTIMATE STRENGTH σ_{UTS} (ksi)		ELONGATION % e	
			RANGE MAX.-MIN.	AVERAGE σ_{ys}	RANGE MAX.-MIN.	AVERAGE σ_{UTS}	RANGE MAX.-MIN.	AVERAGE % e
44; 46.	C	TX	216 → 211	213.5	334 → 329	331.5	13.94 → 12.47	13.205
33; 43; 48.	C	LY	216 → 204	208.67	331 → 322	326.67	14.40 → 12.58	13.69
45.	C	TZ	199	199	331	331	12.50	12.50
47.	C	LZ	198	198	332	332	10.37	10.37
36; 38; 39.	S	TX	202 → 201	201.5	332 → 324	329	14.75 → 12.70	13.91
34°; 40.	S	LY	202	202	325	325	12.81	12.81
35; 37; 41.	S	TZ	212 → 206	208.67	334 → 332	333	12.34 → 9.90	11.29
42.	S	LZ	190	190	333	333	13.47	13.47

° Invalid test.

TABLE V B

TABLE V B

PLATE #	S-II 2							
			YIELD STRENGTH σ_{ys} (ksi)		ULTIMATE STRENGTH σ_{UTS} (ksi)		ELONGATION % e	
SPECIMEN #	LOCATION	ORIENTATION	RANGE MAX.-MIN.	AVERAGE σ_{ys}	RANGE MAX.-MIN.	AVERAGE σ_{UTS}	RANGE MAX.-MIN.	AVERAGE % e
79; 81°; 84°.	C	TX	207	207	340	340	15.04	15.04
82; 86°.	C	LY	202	202	330	330	13.65	13.65
80; 83; 85.	C	TZ	220 → 178	197	268 → 214	249.67	5.50 → 2.60	4.10
No specimen	C	LZ	--------	---	--------	------	---------	----
87°; 92.	S	TX	182	182	219	219	1.88	1.88
89°; 91.	S	LY	210	210	333	333	13.89	13.89
88.	S	TZ	210	210	288	288	7.89	7.89
90; 93.	S	LZ	225 → 198	211.5	337 → 300	318.5	8.84 → 5.73	7.29

°Invalid test.

TABLE VI A

PLATE #	S-III 1								
SPECIMEN #	LOCATION	ORIENTATION	YIELD STRENGTH σ_{ys} (ksi)		ULTIMATE STRENGTH σ_{UTS} (ksi)		ELONGATION % e		
			RANGE MAX.-MIN.	AVERAGE σ_{ys}	RANGE MAX.-MIN.	AVERAGE σ_{UTS}	RANGE MAX.-MIN.	AVERAGE % e
51; 52; 53.	C	TX	212 → 200	205.33	327 → 323	325.33	13.68 → 11.40	12.85
50; 54.	C	LY	203 → 200	201.5	331 → 322	326.5	13.68 → 13.24	13.46
55; 56.	C	TZ	214 → 199	206.5	334 → 333	333.5	13.48 → 12.12	12.8
57.	C	LZ	211	211	325	325	7.25	7.25
59; 61.	S	TX	218 → 206	212	330 → 326	328	14.40 → 10.88	12.64
49; 58; 63.	S	LY	216 → 186	206	337 → 204	290.33	13.27 → 11.92	12.60
60.	S	TZ	214	214	339	339	11.36	11.36
62.	S	LZ	212	212	307	307	5.28	5.28

TABLE VI A

TABLE VI B

TABLE VI B

PLATE #	S-III 2							
SPECIMEN #	LOCATION	ORIENTATION	YIELD STRENGTH σ_{ys} (ksi) RANGE MAX.-MIN.	YIELD STRENGTH AVERAGE σ_{ys}	ULTIMATE STRENGTH σ_{UTS} (ksi) RANGE MAX.-MIN.	ULTIMATE STRENGTH AVERAGE σ_{UTS}	ELONGATION % e RANGE MAX.-MIN.	ELONGATION AVERAGE % e
74°; 77.	C	TX	212	212	329	329	17.24	17.24
73°; 78.	C	LY	221	221	331	331	12.28	12.28
75.	C	TZ	194	194	262	262	5.01	5.01
76.	C	LZ	226	226	327	327	5.04	5.04
65°; 66°; 68.	S	TX	N/A	N/A	302	302		8.4
64; 70.	S	LY	225 → 207	216	328 → 324	326	11.93 → 11.82	11.88
67; 69; 71.	S	TZ	213 → 201	205	334 → 257	288.67	12.42 → 5.22	7.69
72.	S	LZ	216	216	292	292	4.52	4.52

°Invalid test.　　N/A - Not Available.

TABLE VII

TABLE VII SUMMARY OF THE MECHANICAL PROPERTY AVERAGES DETERMINED BY DLT TEST FOR SPECIMENS FROM DIFFERENT PLATES OF ESR AISI 4340 STEEL (H_{RC} ≈57) W.R.T. ORIENTATION

ORIENTATION	T-X			L-Y			T-Z AND L-Z		
PLATES #	YIELD STRENGTH σ_{ys} (ksi)	ULTIMATE TENSILE STRENGTH σ_{UTS} (ksi)	% ELONGATION %e (in)	YIELD STRENGTH σ_{ys} (ksi)	ULTIMATE TENSILE STRENGTH σ_{UTS} (ksi)	% ELONGATION %e (in)	YIELD STRENGTH σ_{ys} (ksi)	ULTIMATE TENSILE STRENGTH σ_{UTS} (ksi)	% ELONGATION %e (in)
SI	210	309	11.63	200.29	311	12.95	203.45	286.16	7.73
SII-1	207.50	330	13.63	207	326.25	13.47	202.17	332.5	11.70
SII-2	194.50	279.50	8.46	206	331.50	13.77	204	279	5.79
Average of SII -1,2 SII	203.17	315.57	12.15	206.67	328	13.57	203.10	305.75	8.75
SIII-1	208	326.4	12.76	204.20	304.80	13.03	210	335.33	9.90
SIII-2	212	329	17.24	217.67	327.67	12.01	208.5	288.17	6.27
Average of SIII -1,2 SIII	208.67	326.83	13.51	209.25	313.38	12.59	209.18	307.73	7.92

TABLE VIII

COMPARISON OF MECHANICAL PROPERTIES OF ESR 4340 STEEL STEP FORGING AT VARIOUS FORGING REDUCTIONS*

SECTION (in.)	ORIENTATION	0.2% YS, ksi RANGE	0.2% YS, ksi AVG	UTS, ksi RANGE	UTS, ksi AVG	%EL RANGE	%EL AVG	%RA RANGE	%RA AVG
8.0 in. (A)	LONG.	204-212	209	314-319	317	11.6-13.2	12.3	41.0-47.5	42.9
	LT	207-220	214	317-319	318	9.9-11.4	10.8	29.3-37.7	34.6
	ST	204-219	213	316-321	319	10-11.7	10.8	30.7-41.1	35.5
				RANGE	[2]	RANGE	[1.5]		
4-3/4 in. (B)	LONG.	214-217	215	315-319	318	11.3-12.8	12.0	40.1-44.2	42.0
	LT	207-216	212	317-319	318	9.8-11	10.2	29.3-35.1	32.3
	ST	208-220	213	313-322	317	7.6-10.2	9.3	21-34.6	27.4
				RANGE	[1]	RANGE	[2.7]		
2-3/4 in. (C)	LONG.	210-216	213	317-320	319	11.6-13.4	12.7	41-44.8	43.6
	LT	208-216	213	317-319	318	10.2-12.8	11.0	28.7-38.3	33.2
	ST	206-222	216	316-322	319	5.4-9	7.3	12.3-25.9	20.0
				RANGE	[1]	RANGE	[5.4]		
1.9 in. (SIII)	TX		209		327		13.5		
	LY		209		313		12.6		
	TZ/LZ		209		308		7.9		
				RANGE	[19]	RANGE	[4.6]		
1.0 in. (SII)	TX		203		316		12.2		
	LY		207		328		13.6		
	TZ/LZ		203		306		8.8		
				RANGE	[22]	RANGE	[4.8]		
0.4 in. (SI)+	TX		206		307		11.1		
	LY		200		311		13.0		
	TZ/LZ		202		285		7.4		
				RANGE	[26]	RANGE	[5.6]		

[ ] Indicates range of averages w.r.t. orientation.

\+ Cross rolled ESR 4340 plate from separate heat.

* Incorporates data supplied by AMMRC (Mr. A. Anctil).

TABLE IX

HARDNESS AND IMPACT ENERGY OF
ESR 4340 STEEL STEP FORGING*

SECTION IN.		ORIENTATION	HRC	RANGE ft-lbs	IMPACT ft-lbs	
		LONG.	56	14.2-16.8	15.6	
8	A	LT	56	9.5-15.8	12.8	A
		ST	56	11.5-16.8	15.1	
		LONG.	56	16.3-19.0	18.0	
4-3/4	B	LT	56	13.9-16.0	15.1	B
		ST	56	11.5-17.1	14.4	
		LONG.	56	13.6-19.0	16.5	
2-3/4	C	LT	56	11.8-17.7	14.8	C
		ST	56	7.6-12.6	10.2	

*Data supplied by AMMRC (Mr. A. Anctil).

TABLE X

DOUBLE TORSION TEST RESULTS FOR BOTH REGULAR & MINIATURE SIZE SPECIMENS OF ESR-AISI 4340 STEEL ($H_{RC} \approx 54$)

Specimen #	Plate	Crack Plane Orientation	Minimum K_Q $\text{Ksi}\sqrt{\text{in}}$ (f)	Minimum K_Q $\text{Ksi}\sqrt{\text{in}}$ (Nf)	Maximum K_Q $\text{Ksi}\sqrt{\text{in}}$ (f)	Maximum K_Q $\text{Ksi}\sqrt{\text{in}}$ (Nf)	Average K_Q $\text{Ksi}\sqrt{\text{in}}$ (f)	Average K_Q $\text{Ksi}\sqrt{\text{in}}$ (Nf)
REGULAR SIZE DT								
1	S-I	T - L	°	--		--	*	--
2	S-I	T - L	58.40	61.98	64.36	66.75	62.00[5]	64.72[5]
3	S-I	L - T	58.65	62.24	60.44	68.22	60.80[5]	64.78[4]
4	S-I	L - T	65.83	67.02	65.83	67.02	65.83[4]	67.02[3]
5	S-II	T - L	51.46	53.86	62.24	62.83	56.97[5]	59.50[5]
6	S-II	L - T	58.65	59.84	65.83	67.02	62.00[5]	63.20[5]
7	S-III	T - L	58.25	59.85	61.00	61.00	58.00[4]	60.25[3]
8	S-III	L - T	58.88	62.48	63.43	67.02	61.25[4]	64.51[4]
9	S-III	T - L	63.43	64.63	65.82	68.22	64.75[5]	66.54[5]
10	S-II	T - L	59.84	60.80	64.24	63.43	61.04[3]	62.15[3]
11	S-II	L - T	56.25	61.34	59.84	61.34	57.15[4]	61.34[1]
MINIATURE								
A	S-III	S - T	+	--		--		--
B Θ	III	L - T	44.3	47.56	50.8	53.3	48.48[3]	51.12[3]
C Θ	III	L - T	47.56	50.84	47.88	50.84	47.66[3]	50.84[2]
D	III	L - T	54.12	57.07	57.40	59.04	55.50[3]	57.80[3]
E	III	T - L	+	--		--		--
F	III	T - L	57.40	59.86	60.68	65.27	58.75[3]	61.95[3]
G Θ	III	L - T	49.20	53.80	50.02	54.12	49.47[3]	54.00[3]
H	S-I	T - L	57.40	59.86	59.04	61.50	58.40[3]	60.70[3]
I	S-I	L - T	59.04	60.70	59.04	60.70	59.04[3]	60.70[3]
J	S-III	S - T	50.84	52.48	52.48	55.76	51.38[3]	54.12[3]

° Results disregarded as method of observation was changed.
* Average taken from given number of observations.
(f) Fatigue precracked
(nf) Non fatigue precracked
\+ Specimens failed during testing.
Θ Different method of fatigue precracking was used.

TABLE XI A

SUMMARY OF DT TEST RESULTS FOR REGULAR SIZE SPECIMENS
WITH RESPECT TO PLATE AND CRACK PLANE ORIENTATION.
MATERIAL--ESR-AISI 4340 STEEL ($H_{RC} \approx 54$)

CPO* / PLATE	L - T K_Q Ksi $\sqrt{in}$		T - L K_Q Ksi $\sqrt{in}$	
	Fatigue Precracked	Non-fatigue Precracked	F	NF
S-I	63.03	65.74	62.00	64.72
S-II	59.80	62.90	58.50	60.50
S-III	61.25	64.51	61.75	64.18

*CPO - Crack Plane Orientation

TABLE XI B

SUMMARY OF DT TEST RESULTS FOR MINIATURE SIZE SPECIMENS
WITH RESPECT TO PLATE AND CRACK PLANE ORIENTATION.
MATERIAL--ESR-AISI 4340 STEEL ($H_{RC} \approx 54$)

CPO* / PLATE	L - T K_Q Ksi$\sqrt{in}$		T - L K_Q Ksi$\sqrt{in}$		S - T K_Q Ksi$\sqrt{in}$	
	F	NF	F	NF	F	NF
S-I	59.04	60.70	58.40	60.70	--	--
S-II	--	--	--	--	--	--
S-III	57.80	55.5	58.70	61.90	51.40	54.10

*CPO - Crack Plane Orientation

TABLE XII

CT TEST RESULT FOR ALL SPECIMENS WITH DIMENSIONAL DETAILS.
MATERIAL--ESR 4340 STEEL ($H_{RC} \approx 54$)

Specimen Number	Plate	CPO	Measured Crack Length a in.	Thickness of the Specimen B in.	Specimen Width W in.	$\frac{a}{W}$	$f\left(\frac{a}{W}\right)$	P_Q lbf	$K_Q = \frac{P_Q}{BW^{1/2}} f\left(\frac{a}{W}\right)$ Ksi$\sqrt{in}$
1	S-I	L-T	0.4275	0.4	1.2125	0.35	6.297	3828	54.5
2	S-I	T-L	0.4125	0.4	1.2125	0.34	6.233	4136	58.5
3	S-II	L-T	1.0625	0.875	1.75	0.607	14.03	3872	47.05
4	S-II	L-T	1.0375	0.875	1.75	0.593	13.28	4290	49.32
5	S-III	L-T	1.325	1.5	3.00	0.44	8.15	13,420	42.08

Notes: (i) $\frac{a}{W}$ ratios in the above table do not satisfy the limits ($0.45 < \frac{a}{W} < 0.55$) imposed by ASTM-E 399-78 standard.

(ii) Results are for single tests.

TABLE XIII

RESULTS OF TESTS USING MINIATURE DT SPECIMENS WITH CHEVRON & ELLIPTICAL PRECRACKS--PLATE S-III WITH CPO AS L-T, MATERIAL--ESR-AISI 4340 STEEL ($H_{RC} \approx 54$)

SPECIMEN	FATIGUE PRECRACK GEOMETRY	MINIMUM K_Q Ksi$\sqrt{in}$		MAX. K_Q Ksi$\sqrt{in}$		AVE. K_Q Ksi$\sqrt{in}$	
		F	NF	F	NF	F	NF
B, C, G	CHEVRON	44.3	47.56	50.8	54.12	48.5[9]*	51.98[9]
D	ELLIPTICAL	54.12	57.07	57.40	59.04	55.5[3]	57.8[3]

* Average of so many observations.

TABLE XIV

COMPARISON OF K_Q RESULTS OBTAINED USING DIFFERENT TEST METHODS FOR PLATE S-I. MATERIAL ESR-AISI 4340 STEEL (H_{RC} = 54)

METHOD	NUMBER OF VALUES	CPO	K_Q Ksi$\sqrt{in}$	REMARKS
DT	9	L-T	63.0	--
	5	T-L	62.0	--
mDT	3	L-T	59.0	--
	3	T-L	58.4	--
CT	1	L-T	54.5	a/w = 0.35
	1	T-L	58.5	a/w = 0.34
IC	5	L-T	51.4	results of tests
	5	T-L	52.7	conducted at AMMRC

All specimens experienced fatigue precracking prior to testing.

TABLE XV

RESULTS OF TENSILE TESTS ESR 4340

BAR NO.	ORIENTATION	FROM PLATE	ORIGINAL DIA. (in)	ORIGINAL AREA (in^2)	YIELD STRENGTH (ksi)	ULT. STRENGTH (ksi)	FRACT. STRENGTH (ksi)	ELONGATION (%)
A	Longitudinal	SI	0.2497	0.0490	202	306	235	15
B	Longitudinal	SI	0.2497	0.0490	201	310	224	15
D	Long Transverse	SI	0.2503	0.0492	202	309	254	13
C	Long Transverse	SI	0.2496	0.0489	204	309	245	14
U	Longitudinal	SIII-2	0.2490	0.0487	197	326	253	16
V	Long Transverse	SII-2	0.2492	0.0488	193	322	277	12
W	Long Transverse	SIII-2	0.2490	0.0487	200	322	271	11
X	Longitudinal	SIII-1	0.2496	0.0489	198	323	252	15
Y	Long Transverse	SII-1	0.2488	0.0486	199	325	273	12
Z	Longitudinal	SII-1	0.2488	0.0486	197	323	257	12

DISTRIBUTION LIST

No. of Copies	To
1	Office of the Under Secretary of Defense for Research and Engineering, The Pentagon, Washington, D. C. 20301
12	Commander, Defense Technical Information Center, Cameron Station, Building 5, 5010 Duke Street, Alexandria, Virginia 22314
	Metals and Ceramics Information Center, Battelle Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201
1	ATTN: J. H. Brown, Jr.
	Deputy Chief of Staff, Research, Development, and Acquisition, Headquarters, Department of the Army, Washington, D. C. 20310
1	ATTN: DAMA-ARZ
	Commander, Army Research Office, P. O. Box 12211, Research Triangle Park, North Carolina 27709
1	ATTN: Information Processing Office
	Commander, U. S. Army Materiel Development and Readiness Command, 5001 Eisenhower Avenue, Alexandria, Virginia 22333
1	ATTN: DRCLDC
	Commander, U. S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, Maryland 21005
1	ATTN: DRXSY-AA, Director
	Commander, U. S. Army Missile Command, Redstone Arsenal, Alabama 35809
1	ATTN: Technical Library
1	DRSMI-CS, R. B. Clem
	Commander, U. S. Army Armament Research and Development Command, Dover, New Jersey 07801
2	ATTN: Technical Library
1	DRDAR-SCM, J. D. Corrie
1	Dr. J. Frasier
	Commander, U. S. Army Tank-Automotive Research and Development Command, Warren, Michigan 48090
1	ATTN: DRDTA-RKA
2	DRDTA-UL, Technical Library
1	DRDTA-RCK, D. W. Mackeiwicz
	Commander, U. S. Army Foreign Science and Technology Center, 220 7th Street, N. E., Charlottesville, Virginia 22901
1	ATTN: Military Tech, Mr. Marley
	Director, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604
1	ATTN: DAVDL-E-MOS
1	DAVDL-EU-TAP

No. of Copies	To
	U. S. Army Aviation Training Library, Fort Rucker, Alabama 36360
1	ATTN: Building 5906-5907
	Director, U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland 21005
1	ATTN: DRDAR-VL, W. S. Thompson
	U. S. Army Aviation Research and Development Command, P.O. Box 209, St. Louis, Missouri 63166
1	ATTN: DRDAV-ASE
1	DRDAV-ASH
1	DRDAV-EI
1	DRDAV-EXH
	Naval Research Laboratory, Washington, D. C. 20375
1	ATTN: Dr. J. M. Krafft - Code 5830
1	Code 2627
	Chief of Naval Research, Arlington, Virginia 22217
1	ATTN: Code 471
	Director, Structural Mechanics Research, Office of Naval Research, 800 North Quincy Street, Arlington, Virginia 22203
1	ATTN: Dr. N. Perrone
	Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio 45433
2	ATTN: AFML/MXE/E. Morrissey
1	AFML/LC
1	AFML/LLP/D. M. Forney, Jr.
1	AFML/MBC/Mr. Stanley Schulman
1	AFML/MXE/A. Olevitch
	National Aeronautics and Space Administration, Washington, D. C. 20546
1	ATTN: Mr. B. G. Achhammer
1	Mr. G. C. Deutsch - Code RW
	National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama 35812
1	ATTN: R. J. Schwinghammer, EH01, Dir, M&P Lab
1	Mr. W. A. Wilson, EH41, Bldg. 4612
	Chief of Naval Operations, Washington, D.C. 20350
1	ATTN: OP-987, Director
	Aeronautical Systems Division (AFSC), Wright-Patterson Air Force Base, Ohio 45433
1	ATTN: ASD/ENFEF, D. C. Wight
1	ASD/ENFTV, D. J. Wallick
1	ASD/XRHD, G. B. Bennett

No. of Copies	To
	Air Force Armament Laboratory, Eglin Air Force Base, Florida 32542
1	ATTN: AFATL/DLYA, V. D. Thornton
	Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio 45433
1	ATTN: AFFDL/FES, G. W. Ducker
1	AFFDL/FES, J. Hodges
1	AFFDL/TST, Library
	Air Force Test and Evaluation Center, Kirtland Air Force Base, New Mexico 87115
1	ATTN: AFTEC-JT
	Armament Development and Test Center, Eglin Air Force Base, Flordia 32542
1	ATTN: ADTC/TS
	NASA - Ames Research Center, Mail Stop 223-6, Moffett Field, California 94035
1	ATTN: SC, J. Parker
	NASA - Ames Research Center, Army Air Mobility Research and Development Laboratory, Mail Stop 207-5, Moffett Field, California 94035
1	ATTN: SAVDL-AS-X, F. H. Immen
	NASA - Johnson Spacecraft Center, Houston, Texas 77058
1	ATTN: JM6
1	ES-5
	Naval Air Development Center, Warminster, Pennsylvania 18974
1	ATTN: Code 063
	Naval Air System Command, Department of the Navy, Washington, D.C. 20360
1	ATTN: AIR-03PAF
1	AIR-5203
1	AIR-5204J
1	AIR-530313
	Naval Material Command, Washington, D.C. 20360
1	ATTN: MAT-0331
	Naval Post Graduate School, Monterey, California 93948
1	ATTN: Code 57BP, R. E. Ball
	Naval Surface Weapons Center, Dahlgren Laboratory, Dahlgren, Virginia 22448
1	ATTN: DG-34, N. Rupert
1	Library
	Naval Weapons Center, China Lake, California 93555
1	ATTN: Code 40701
1	Code 408
	Commander, Rock Island Arsenal, Rock Island, Illinois 61299
1	ATTN: DRSAR-PPV

No. of Copies	To
	Armament Systems, Inc., 712-F North Valley, Anaheim, California 92801
1	ATTN: J. Musch
	Beech Aircraft Corporation, 9709 E. Central Avenue, Wichita, Kansas 67206
1	ATTN: Engineering Library
	Bell Helicopter Company, A Textron Company, P.O. Box 482, Fort Worth Texas 76101
1	ATTN: J. R. Johnson
	Boeing Vertol Company, A Division of the Boeing Company, P.O. Box 16858, Philadelphia, Pennsylvania 19142
1	ATTN: J. E. Gonsalves, M/S P32-19
	Calspan Corporation, P.O. Box 235, Buffalo, New York 14221
1	ATTN: Library
	Cessna Aircraft Company, Wallace Division, P.O. Box 1977, Wichita, Kansas 67201
1	ATTN: B. B. Overfield
	Fairchild Industries, Inc., Fairchild Republic Company, Conklin Street, Farmingdale, Long Island, New York 11735
1	ATTN: Engineering Library, G. A. Mauter
	Falcon Research and Development Company, 601 San Pedro, N.E., Suite 205, Albuquerque, New Mexico 87108
1	ATTN: W. L. Baker
	General Dynamics Corporation, Convair Division, P.O. Box 80877, San Diego, California 92138
1	ATTN: Research Library, U. J. Sweeney
	General Research Corporation, Science and Technology Division, 5383 Hollister Avenue, P.O. Box 3587, Santa Barbara, California 93105
1	ATTN: R. Rodman
	Gruman Aerospace Corporation, South Oyster Bay Road, Bethpage, New York 11714
1	ATTN: Technical Information Center, J. Davis
	Hughes Helicopters, A Division of Summa Corporation, Centinela & Teale Street, Culver City, California 90230
1	ATTN: Library, 2/T2124, D. K. Goss
1	Mr. J. French
1	Mr. L. Soffa
1	Mr. A. Edwards
1	Mr. W. Jarrett
	IIT Research Institute, 10 West 35th Street, Chicago, Illinois 60616
1	ATTN: K. McKee

No. of Copies	To
	Kaman Aerospace Corporation, Old Winsor Road, Bloomfield, Connecticut 06002
1	ATTN: H. E. Showalter
	Lockheed-California Company, A Division of Lockheed Aircraft Corporation, Burbank, California 91503
1	ATTN: Technological Information Center, 84-40, U-35, A-1
	LTV Aerospace Corporation, Vought Systems Division, P.O. Box 5907, Dallas, Texas 75222
1	ATTN: J. A. Fouse
	Martin Marietta Corporation, Orlando Division, P.O. Box 5837, Orlando, Florida 32805
1	ATTN: Library, M. C. Griffith
	McDonnell Douglas Corporation, 3855 Lakewood Boulevard, Long Beach, California 90846
1	ATTN: Technical Library, C1 290/36-84
	Northrop Corporation, Aircraft Division, 3901 W. Broadway, Hawthorne, California 90250
1	ATTN: Mgr. Library Services, H. W. Jones
	Parker Hannifin Corporation, Bertea Control Systems Division, 18001 Von Karman Avenue, Irvine, California 92715
1	ATTN: C. Beneker
	Rockwell International Corporation, Los Angeles Aircraft Division, B-1 Division, International Airport, Los Angeles, California 90009
1	ATTN: W. L. Jackson
	Sikorsky Aircraft, A Division of United Aircraft Corporation, Main Street, Stratford, Connecticut 06602
1	ATTN: J. B. Faulk
1	W. G. Dignam
	Teledyne CAE, 1330 Laskey Road, Toledo, Ohio 43697
1	ATTN: Librarian, M. Dowdell
	The Boeing Company, Wichita Division, 3801 S. Oliver Street, Wichita, Kansas 67210
1	ATTN: Library
	Director, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172
2	ATTN: DRXMR-PL
1	DRXMR-PR
1	DRXMR-PD
1	DRXMR-AP
10	DRXMR-EM, Mr. A. Anctil